Battery Development Impact on Potential New Missions

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How To Enable New Missions?

Higher onboard power. But how to generate it?

Current missions are constricted by use of up to 27 kW. The key to enable (1) larger volume payloads for new missions, and/or (2) cost reduction is <u>increased volumetric specific power</u> in solar arrays with <u>higher specific energy</u> in battery systems.

The AFRL/RV High Power Solar Array (HPSA) and DARPA High Power Generation System (HPGS) solar array projects demonstrate promise to deliver up to <u>500 kW</u> on-orbit in <u>existing</u> launch vehicle fairings using thin, flexible arrays of 12-14 um thick solar cells.

Revolutionary Energy Storage: Li-ion Cell Development

- Current state-of-practice - Ni-H specific energy: 55-75 W-h/kg
- Revolutionary development effort: Li-ion specific energy: 100-150 W-h/kg
- The change in technology from Ni-H to Li-ion represents a possible 30% to 270% decrease in battery mass/volume for future missions which may enable new concepts, or establish cost reduction for existing concepts

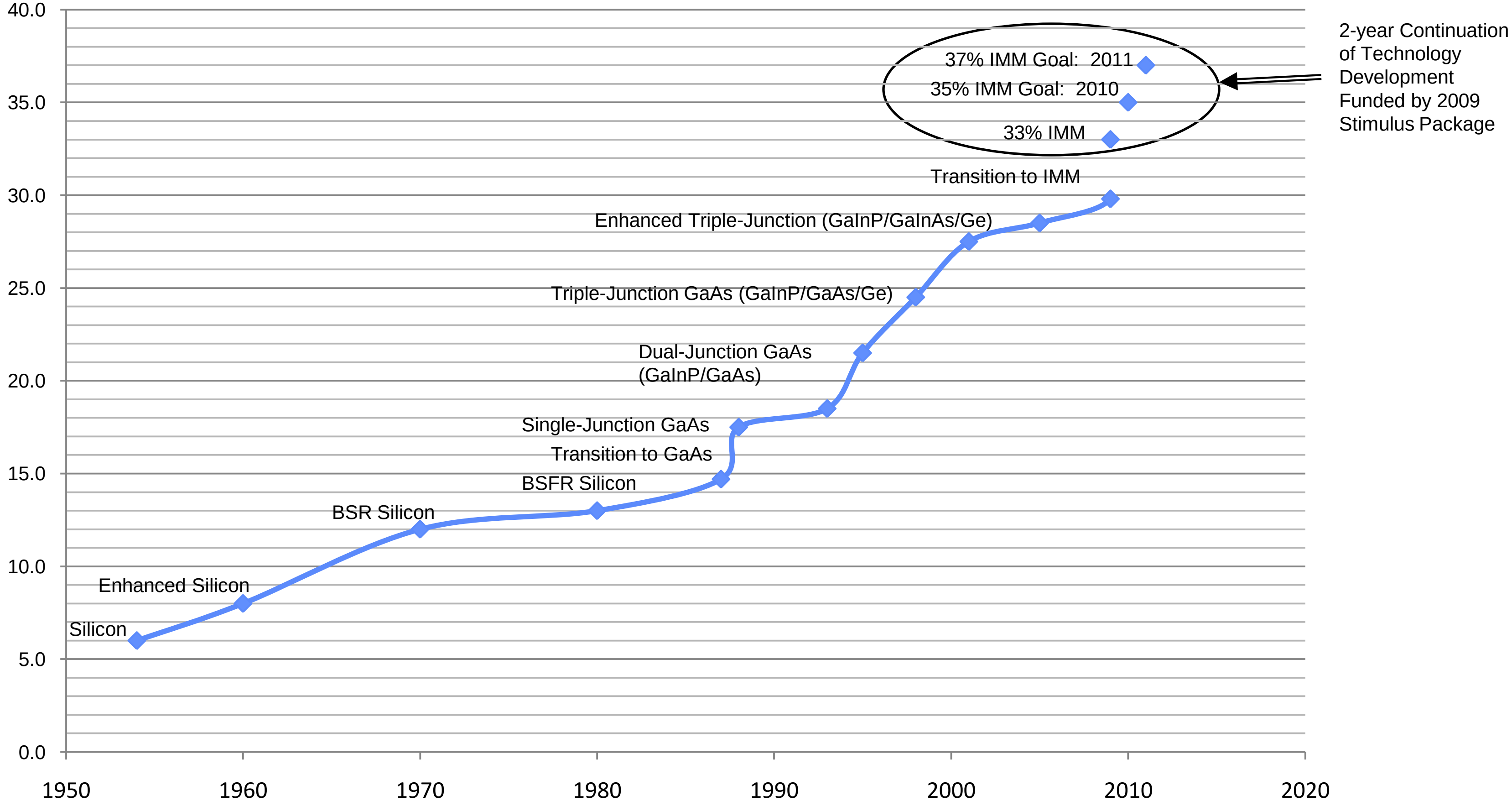
Recent Space Solar Power Generation Technology Developments

- **Science Supports the Solution – Flexible, High Efficiency Solar Cell Research & Development**
  - Inverted Metamorphic (IMM) 37% efficient AM0 cell development program fully-funded at Emcore, Spectrolab – goals are 3J - 33%, 4J - 35%, 5J – 37% by 2011
    - POC Alex Howard, AFRL/RV
  - BOL 40% efficiency concepts now being explored

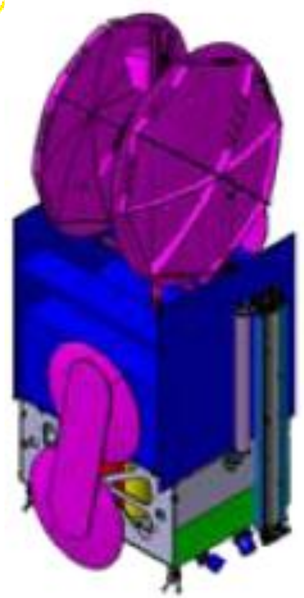
- **Engineering Supports the Solution – Engineered, Flexible Structural Materials Decrease Solar Array Thickness**
  - 16X specific power HPSA concept – flexible, thin array projected to deliver 450kW with a 33% efficient cell, phase II complete – phase III in planning stages
    - POC Paul Hausgen, AFRL/RV
  - 7x specific power HPGS concept - "Survivable" concentrator array projected to deliver 175 kW with a 33% efficient cell, fully-funded phase II initiated (http://boeing.mediaroom.com/index.php?s=43&item=729)(http://www.emcore.com/news_events/release?y=2009&news=228)
    - POC Jess Sponable, DARPA

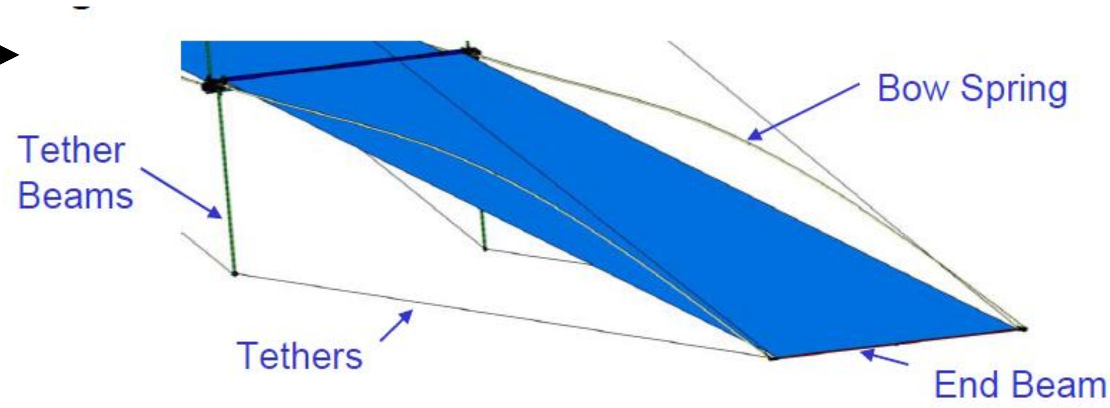
Production Solar Cell Efficiency

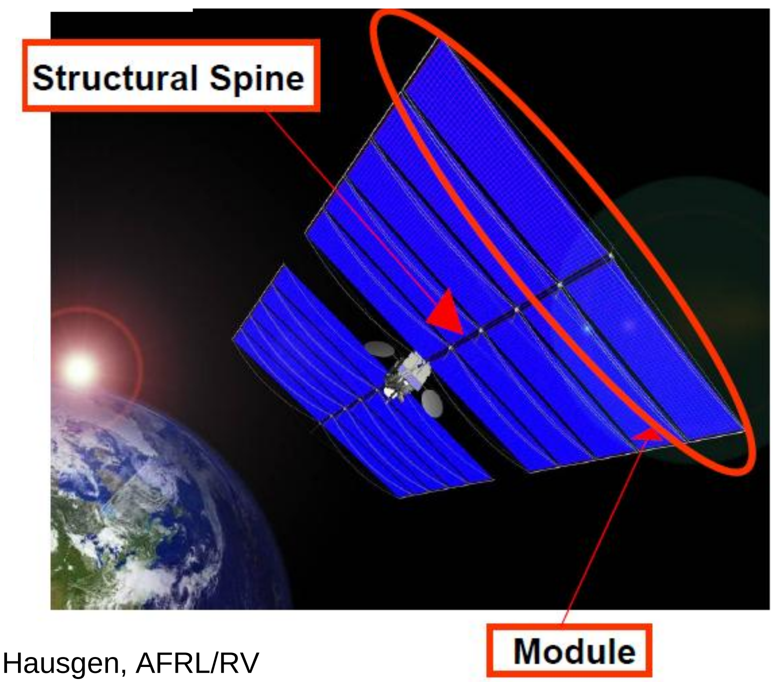
Inverted Metamorphic (IMM) Process Promises Rapid Increases in Efficiency



HPSA on Notional Satellite*

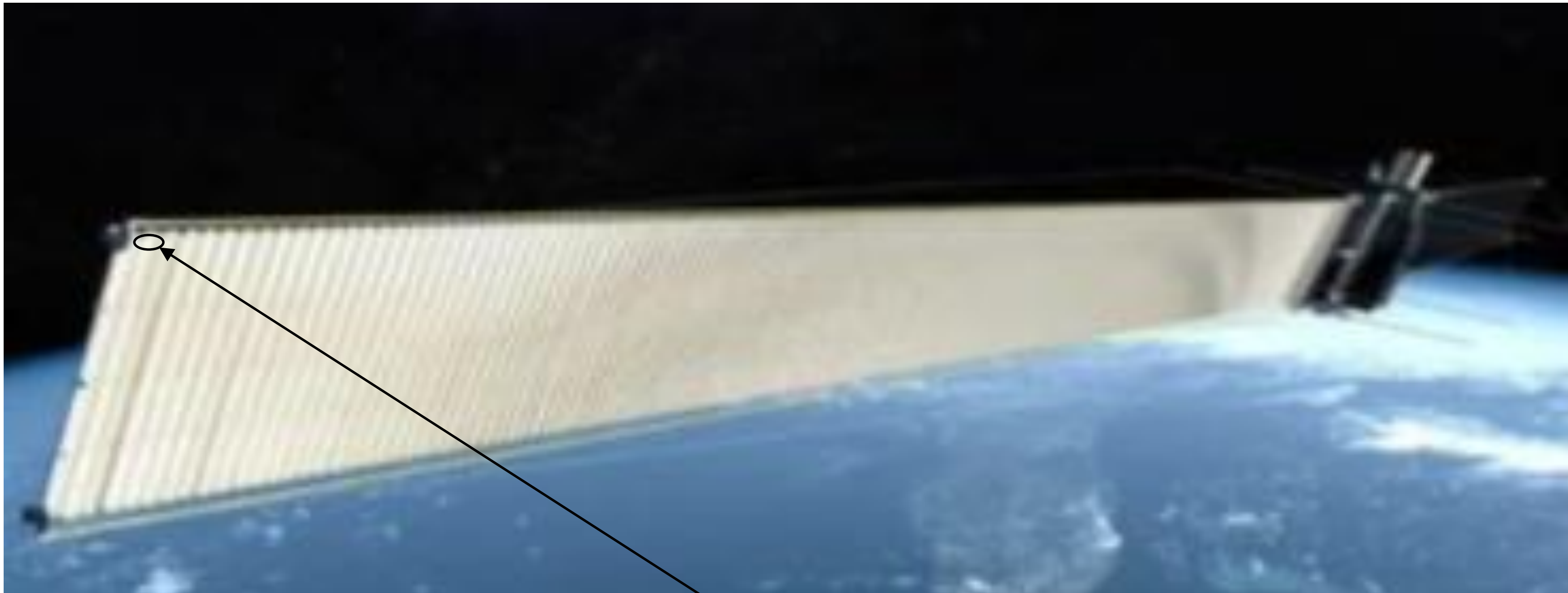




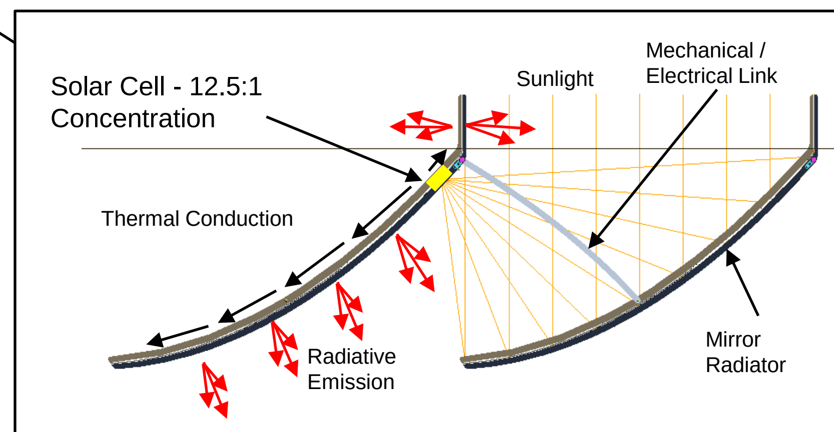


*Conceptual drawings courtesy of Paul Hausgen, AFRL/RV

HPGS Concept for DARPA FAST*



28% solar cell efficiency is the current state-of-practice. HPGS uses a solar concentrator approach to minimize photovoltaic cost, maximize survivability. Concentration improves efficiency, so the 37% cell may engage 38-39% of incoming power in this design.



*Conceptual drawings courtesy of Jess Sponable, DARPA

Further Technology Development Could Increase Volumetric Specific Power

If the existing, funded, Emcore and Spectrolab development programs are able to achieve the 37% AM0 efficiency goal in 2 years:

- The HPSA concept could deliver satellite power up to approximately 500kW in one launch vehicle
- The HPGS concept could deliver satellite power up to approximately 200kW in one launch vehicle
- Both concepts are scalable from 25kW up

New Missions Enabled by High Power, Low Volume Solar Arrays and High Specific Energy Li-ion Batteries*

Laser Mission	Impact
– Satellite-to-Submarine Communication	Incremental
– Laser Communications	Enabling
– 3D Doppler Wind LIDAR	Minimal
– Remote Detection of Chemical Species	Enabling
– Water Vapor Atmospheric Profile	Enabling
– Terrestrial Imaging LIDAR – 450 km	Enabling
– Terrestrial Imaging LIDAR – 1500 km	Enabling

*Courtesy of Jay Penn, The Aerospace Corporation

New Missions Enabled by High Power, Low Volume Solar Arrays and High Specific Energy Li-ion Batteries*

Mission	Impact
Radar	
– Ground Moving Target Indicator (GMTI)	Incremental
– Airborne Moving Target Indicator (AMTI)	Enabling
Space Utilities	
– Space Solar Power Demonstrator	Enabling
Electric Power Applications	
– GEO Sat on Minotaur IV Class	Enabling
– GEO Sat on EELV Heavy (100 kW GEO comm)	Enabling

*Courtesy of Jay Penn, The Aerospace Corporation

Electric Propulsion Applications

- **What does the combination of high power and electric propulsion potentially offer?**
  - **The possibility of avoiding chemical propellant issues (consumable mass) for multiple occasions of**
    - **Orbit Raising**
    - **Plane Changes**
    - **Orbit Changes**

- **How is this revolutionary?**
    - **Targeting of specific areas on earth**
      - **One satellite could globally perform a single mission**
    - **Evasion of satellite threats**
      - **Avoidance of threatening environments**
    - **Travel to specific orbital locations in three-dimensional space**
      - **e.g. “space junk” collection and disposal**

Notional Launch Vehicle Cost Savings*

One potential cost savings of volume reduction is found in changing to a different class of launch vehicle or using a dual-manifest approach. Depending on size of mission, change of vehicle could result in potential savings of $38M in Delta IV, $40M in Delta IV Heavy, $55M in Falcon, $60M in Atlas, and $85M between Delta IV Medium and Delta IV Heavy.

Vehicle	Configuration	Notional Cost ($M)
Athena	II	$40-45
Atlas V	400 Series	$97-135
Atlas V	500 Series	$113-156
Delta II	7326-10	
Delta II	7425-10	$48-63
Delta II	7925-10	
Delta II	7925H-10	
Delta IV	Medium (4,0)	
Delta IV	Medium+ (4,2)	$97-135
Delta IV	Medium+ (5,2)	
Delta IV	Medium+ (5,4)	
Delta IV	Heavy	$220-260
Falcon	1	$7-9
Falcon	1e	$9-12
Falcon	9	$35-55
Falcon	9 Heavy	$55-90
Minotaur	I	$17-23
Minotaur	IV	$24-30
Pegasus	XL	$17-25
Taurus	Standard	$22-28
Taurus	XL	$26-30

Delta II Flyout Completed

*Data courtesy of Jay Penn, The Aerospace Corporation

Way-Forward

The industrial base's current core competency is to produce rigid solar cells for rigid flat-plate solar panels, and Ni-H batteries

The SMC Chief Engineer's Office advocates future funding to develop manufacturing capability for flexible solar cells/solar panels with increased volumetric specific power, and high specific energy Li-ion battery concepts

Summary

- **Radically new missions are now being considered possible as it has been demonstrated that there will soon be "new tools in the toolbox"**

- **Significant cost reductions will be possible due to changes in launch vehicle or launch strategy enabled by these new tools**

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